

Variable Speed Control: Technologies and Practice

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Abstract: Static speed limit signs are conventionally used in the U.S. to assist motorists in safe selection of speeds. Although appropriate to use under near ideal conditions, such signs fail to provide accurate information on speed selection when traffic and environmental conditions are less than ideal. This paper documents the findings from a state-of-the-practice review on variable speed limit systems. Such systems dynamically update posted speed limits to better reflect prevailing traffic and environmental conditions. The paper reviews and compares characteristics of variable speed limit systems, and discusses potential benefits and limitations associated with their deployment. Examples of domestic and international applications of variable speed limit systems are presented, together with an assessment of their potential capabilities towards enhancement of traffic operations.

Key words: Variable speed limits, variable message signs, posted speed limit, traffic control devices.

1. Introduction

Operational efficiency and traffic safety greatly depend on the proper selection of travel speed.

Traditionally, static posted speed limits are placed on the roadside to assist motorists in this process. Static speed limit signs display the limit established by law, or by regulation after an engineering and traffic investigation has been made in accordance with established traffic engineering practices. Six factors shall be taken into account when determining the proper numerical value for a speed zone (1):

1. Road surface, shoulder condition, grade, alignment and sight distance;
2. The 85-percentile speed and pace speed;
3. Roadside development, culture, and roadside friction;
4. Safe speed for curves or obstacles with the zone;
5. Parking practices and pedestrian activity; and
6. Reported accident experiences for a recent 12-month period.

Maximum posted speed limits are applicable under ideal traffic and weather conditions. However, when the conditions are less than ideal, the responsibility of choosing a lower, more appropriate, safe driving speed is placed on the motorist. Static speed limit signs are unable to assist travelers with the challenge of determining a proper maximum safe driving speed under non-ideal conditions. It is equally a problem for police officers to justify citing motorists for driving at speeds that are "unsafe for conditions" because this determination is mostly subjective.

Variable speed limit systems can be utilized to alleviate the problems experienced by the use of static speed limit signs. Variable speed limit systems are a type of Intelligent Transportation System (ITS) that utilizes traffic speed and volume detection, weather information, and road surface condition technology to determine appropriate speeds at which drivers should be traveling, given prevailing roadway and traffic conditions (2).

In Europe and Australia, where such systems are currently operational, the transportation authorities were able to achieve considerable traffic flow and safety benefits by dynamically changing the speed limit based upon real-time traffic and weather information. While variable speed limit systems are still in their infancy in the United States, they hold some promise toward making US highways safer and more user-friendly, and warrant further consideration.

This paper presents features of variable speed limit systems, provides examples of domestic and foreign applications of such systems, and discusses their potential benefits and limitations.

2. Description of Variable Speed Limit Systems

A synergy of a) real-time traffic and weather data collection, b) data processing, and c) dynamic speed limit display is required for proper operation of variable speed limit systems. Various methods and technologies are currently available to support the data collection, processing, and information display functions and are discussed in detail next, together with examples from field operational tests and deployment projects.

2.1 Data Collection Methods

Real-time data collection is very important and is often part of a broader Intelligent Transportation System (ITS) deployment effort in support of Advanced Traffic Management Systems (ATMS) and Advanced Traveler Information Systems (ATIS) user services. The most common method for the collection of real-time traffic information is through the use of inductive loop detectors. Loop detectors are imbedded in the pavement and can provide traffic counts, occupancy, and speed information. Many examples of variable speed limit systems that depend on inductive loop detectors for traffic data collection can be found in the literature. These include an operational test in Colorado, a system on the New Jersey Turnpike, a system on A2 rural freeway between Amsterdam and Utrecht, an extensive urban system on M 25 London Orbital, various applications in Germany's rural autobahn, and a system on F6 Tollway South of Sydney, Australia.

Other methods for collection of dynamic traffic information employed in existing variable speed limit systems include overhead radar, a commonly used approach in the French system deployed in Marseille, and Closed Circuit Television (CCTV), a system available in the United Kingdom. Oftentimes combination of more than one data collection systems is used to improve the accuracy of traffic condition estimation. In the United Kingdom, for example, a combination of data from CCTV and loop detectors is considered, where in the Netherlands a combination of loop detector data and automatic incident detection determines the speed limit selection.

The variable speed limit system in Australia combines traffic data from loop detectors to data from a visibility detector. Visibility sensor technology has been used successfully in other systems including a system in the Netherlands which aims at eliciting safer driving behavior during fog. In this system, if visibility drops below 140 m, posted speed limit is reduced from 100 km/h to 80 km/hr. Further reduction of visibility to 70 m results in a decrease of the posted speed limit to 60 km/hr.

Weather conditions that may adversely affect traffic operations are also monitored through road weather information systems in weather stations. Such systems collect data on various environmental conditions including wind speed and direction, visibility, relative humidity, rain intensity and cumulative precipitation.

Examples of variable speed limit systems that utilize weather information for variable speed limit setting can be found in Arizona, Nevada, Washington State, Finland, and Germany. Other existing systems consider expansions to include weather-related information such as the New Jersey Turnpike system that is planning addition of weather sensing equipment in the near future.

Pavement conditions are also monitored in some current systems and pavement sensors provide real-time information on surface conditions (dry, wet, snowy, iced, salted etc). Such information can be fused with traffic and environmental data to enhance the mechanism for proper selection of driving speeds for given conditions.

Depending on the purpose of the system, additional data may need to be collected. For instance, dynamic warning systems for trucks require information on truck weight and classification in order to identify safe operating speeds for long downgrades. Such systems typically involve weigh in motion (WIM) and automatic vehicle identification (AVI) technologies that provide the required inputs for downhill advisory speed computation and display (3).

2.2 Data Processing Mechanisms

The level of sophistication with respect to speed limit calculation varies considerably among the various systems currently in operation. Typically, an algorithm is run within a computer system at the Traffic Management Center to determine safe speed based on given traffic flow, environmental, and/or pavement conditions. Speed limits are reduced in 5-, or 10-mph increments in the United States and 20 km/h abroad.

Simple matrices of advisory speeds and corresponding conditions are used for maximum speed selection in Washington State and Finland. In the Netherlands, posted speed is determined by a system control algorithm based on 1-minute averages of speed and volume across all lanes. In an application of variable speed control in Nevada, speed limits are computed using a logic tree based on the 85th percentile speed, visibility (in terms of stopping sight distance), and pavement conditions (based on frost, ice, rain, or dry conditions) (4). In Australia, advisory speed calculation is based on the visibility distance and the speed of

the preceding vehicle (4). In the United Kingdom, speed limits are changed according to detected vehicle volumes. The displayed speed changes from 70 mph to 60 mph when volume exceeds 1,650 veh/hr/lane and to 50 mph for volumes over 2,050 veh/hr/lane. The system also monitors traffic speeds and stationary traffic to slow down vehicles that are approaching a queue, and has additional logic to stop frequent fluctuation of speed limits (2).

A pioneering attempt to develop fuzzy control algorithms for speed selection is being carried out by the Northern Arizona University as part of the Arizona DOT funded project Enterprise. Fuzzy logic considers each variable on a gradually changing scale, as opposed to a specific cutoff point for a simple "yes - no" decision. This logic parallels the human decision-making process. The algorithm is trained with a variety of inputs from ADOT road weather stations along the I-40 Corridor as well as traffic speed data. The decision factors for speed reductions utilize the fuzzy logic blending of adverse conditions, in combination with safe speed guidelines developed by highway maintenance staff and state patrol officers (5).

In operational tests that identify vehicle-specific safe operating speeds for commercial vehicles at long downgrades, algorithms have been developed to compute a safe speed based on truck weight, speed, and axle configuration. Such information is gathered by weigh-in-motion (WIM) sensing technologies. Examples of algorithms developed for this type of application can be found in the Green Light Field Operational Test in Oregon (6) and the Dynamic Down Hill Truck Speed Warning System Operational Test in Colorado (7). Currently, British Columbia, and West Virginia are designing and constructing similar systems.

2.3 Dynamic Speed Limit Display

After data processing and speed limit calculation, the new speed limit information is displayed on variable message signs. Some systems provide the ability for manual overrides. This feature offers added flexibility under construction work or lane closure situations, and in the case of system failure. Emergency speeds or other emergency information can be manually displayed in several existing systems in the United States such as in New Jersey, Arizona, Oregon, and Washington.

Appropriate reduced speed limit messages are typically displayed to approaching traffic well in advance of the queue or disturbance by variable message signs (8). The frequency of variable speed limit sign placement varies from two per km (Finland) to one every two km (New Jersey; Washington; Germany). Most applications report approximate variable speed limit sign spacing of one km (Australia, Netherlands, United Kingdom).

Typical speed limit signs found in Europe use fibre optic technology with light emitting diodes (LED). The speed limit consists of a red circle with a white number inside the circle. Its appearance resembles the standard European speed limit sign. In the Netherlands, the speed limit is regulatory and enforced when posted in red circle, and advisory if posted without a circle. In the United Kingdom, flashing warning lights are placed at the upper corners and are activated when the speed limit has been lowered.

The speed limits are most often installed over travel lanes. This practice appears to improve the visibility of the variable speed limit signs over that of the static signs that are found along the roadside. When there is no need for speed limit reduction, the variable speed signs are set at the normal advisory or regulatory speed and serve as reinforcement messages to remind drivers of the safe travel speed (8).

In the United States variable speed limit signs are sometimes placed on the roadside. When not in use, some systems display the normal speed limit, while others remain blank to avoid driver information overload. In the case of truck speed warning systems, each properly weighed truck receives a vehicle-specific message stating the recommended safe speed. Improperly weighed transponder equipped trucks receive a truck specific generic message (such as Steep Downgrade) and trucks without transponders do not receive any messages. Figure 1 shows an example of the truck speed warning system used in Colorado (3).

In many cases variable speed limit signs are used in conjunction with variable message displays that provide warnings of hazardous conditions or display speed reduction warning information. Combination of such systems has been successful in New Jersey, and Finland.



Figure 1. Example of Dynamic Downhill Truck Speed Warning System in Colorado (3).

2.4 Enforcement

With a few exceptions, the speed limits displayed on variable speed limit signs are regulatory and enforceable. Automated enforcement is a common practice abroad and is typically achieved through photo radar technologies. Cameras are mounted on the back of the overhead freeway signs above each lane. Detectors identify vehicles traveling above the speed indicated in the variable sign and the camera takes a picture of the license plate on the back of the vehicle.

The enforcement cameras in the United Kingdom use flashes to provide lighting for the photograph. The camera flash alone (operating without a camera) provide drivers with sufficient indication of enforcement to ensure compliance. A small number of cameras is rotated frequently so that motorists would not know if the flash coming from the camera box meant a picture was taken or not (8). Reports indicate that enforcement is the key to ensuring drivers' compliance with variable speed limits.

3. Assessment of Variable Speed Limit Systems Effectiveness

Implementation of variable speed limit systems usually is considered in order to fulfill one or more of the following purposes:

1. Provide early warning to motorists of slow traffic or hazardous roadway conditions;

2. Influence driver behavior and increase driver motivation to obey the posted speed limit;
3. Minimize crash risk and improve traffic safety;
4. Stabilize and smooth traffic flows.

Regardless of the motivation behind the deployment of variable speed limit systems, objective evaluation studies shall follow to measure the success of variable speed limits in reduction of collisions, improvement of drivers compliance and smoothing of traffic flow. Such studies can provide useful information on potential benefits from, and impediments to technology deployment and can guide U.S. transportation officials on future investment decisions.

The review of the literature overwhelmingly supports the argument that variable speed limit systems are an innovative traffic control approach with many advantages over traditionally used static speed limit signs. With respect to traffic safety, analysis of crash data in Germany has shown that the use of the variable speed limit and speed warning signs has reduced the crash rate by 20 to 30% (2). Studies in the United Kingdom confirmed a 10-15% reduction in crashes as a result of variable speed limit use. A dramatic decrease (25-30%) in the number of rear end crashes on the approaches to freeway queues was also documented. In Colorado, crash records analysis on the I-70 test site of the dynamic downhill truck speed warning system showed that, since system deployment in 1995, truck-related crashes have declined constantly (6-7%) while the volume of truck traffic has increased by an average of 5% per year (3).

As far as user compliance is concerned, the combination of the study system with a camera speed enforcement program lead to very high driver compliance with the speed limit in most of the systems reviewed. Evaluation of the variable speed limit system in the Netherlands concluded that drivers reduced their mean speeds by approximately 8 to 10 km/h in response to the variable speed control. In Finland, for speed limit reduction from 100 km/h to 80 km/h due to slippery road conditions, the mean speed of motor vehicles passing the adaptive speed limit systems dropped by 2.5 km/hr more than in the control road section (9). When the speed limit was reduced from 120 km/h to 100 km/hr due to aquaplaning, the mean speed of traffic dropped by 5.6 km/h in the variable speed limit section (1.2 km/h drop in the control

section). Further reduction of the posted speed limit to 80 km/h resulted in drop of the mean speed by 7.4 km/hr (5.4 km/h drop on the control section).

It was also encouraging to find out that the public acceptance to the system has high. Drivers in the United Kingdom were impressed with the system and 68% of those surveyed recommended expansion of the system in the future. A user acceptance study in Finland, undertaken by the Technical Research Center of Finland, found that 95% of the drivers endorsed the used of speed limits set according to the prevailing road conditions and 81% of the system users thought that the prevailing speed was appropriate (9).

One of the downsides of the variable speed limit system is that drivers come to rely on variable signs to warn of dangers. Consequently, when the signs are blank, they automatically assume that there are no problems. In other words, if the sign fails to operate, however, the driver will not only proceed unaware of the danger, but even worse, he or she will expect that no danger lays ahead.

Another concerned voiced by the opponents of variable speed limit systems in the United States is liability. It is true that variable speed limit systems place more responsibility on the engineers and less on the drivers for proper selection of speed under the prevailing conditions (10). New laws would have to be drawn up assigning responsibilities and outlining proper enforcement practices.

A lack of standards for the use of dynamic message signs has been also identified. As in many other ITS services, it is important to promote uniformity of traffic control applications nationwide, while simultaneously allowing healthy competition among product providers.

5. Summary and Conclusions

Static maximum speed limits in most jurisdictions are posted based on ideal conditions. Such practice offers little assistance to motorists who are required to determine an appropriate driving speed under less than ideal conditions. Furthermore, law enforcement agencies are asked to make a subjective determination

when citing someone going too fast for conditions. This is an undesirable practice that often results in driver confusion and frustration.

In order to assist drivers in proper selection of safe driving speeds, increase traffic safety, and driver respect for speed limit restrictions, real-time variable speed limit systems are desirable that dynamical adjust speed limits in response to changes in traffic and environmental conditions.

The review of the literature and the state-of-the-practice on variable speed limit systems led to the following conclusions and recommendations:

- ❑ National and international experts on variable speed control generally agree that such systems result in considerable traffic flow and safety benefits. Crash reduction by 10-30% was found at sites where variable speed limits were imposed. Reduction of mean speed by 2-8 km/hr was achieved in response to variable speed limit control.
- ❑ Case studies also indicate that the public is in support of variable speed limits and are more responsive to variable maximum speed limits rather than posted static speed limits.
- ❑ Sufficient current traffic and weather information data shall be collected; and reliable and efficient data processing algorithms shall be in place to guarantee calculation of appropriate speed limits for prevailing conditions. Driver compliance with speed control is greatly associated with respect and trust for the system, which in turn, depends on the accuracy and reliability of speed limit estimation.
- ❑ Variable speed limit systems need their own information security and continuity plans to ensure the systems continue to operate effectively and in a reliable manner.
- ❑ Currently, there no standards in the United States for the use of dynamic message signs. The upcoming version of the Manual on Uniform Traffic Control Devices should provide basic guidelines on the use of variable speed limit systems across the nation.
- ❑ Additional operational tests and evaluations studies are needed in the U.S. to clearly document the merits of the adaptive speed limit control for local conditions.

Overall, the experience with the use of variable speed limit signs to date is very positive in terms of safety, operational efficiency, and driver satisfaction. It is believed that U.S. freeway operations could benefit from the use of variable speed limits. However, some issues need to be addressed before such a practice can be implemented nationwide. Among these issues are the legalities associated with variable speed limits, procedures associated with the selection of speed limit and the design of the speed message, and enforcement policies.

5. References

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